Research on specifications of partial re-painting for steel bridges

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ABSTRACT

Paint deterioration and corrosion of steel bridges tend to progress partially, not uniformly. Narrow parts such as edges of steel girders often corrode due to its corrosive environment even if common parts are comparatively sound.

On the other hand, it has been difficult to implement repair painting or re-painting at the narrow parts of bridge due to a difficult condition for surface preparation and painting works, and other matters. Therefore, there are many cases that large-scale re-painting is not conducted until severe deterioration and corrosion are confirmed and existing paint film is often renewed with including comparatively sound one. These methods are not economical from the viewpoint of life cycle cost (LCC) and have danger to lead to the lack of safety of the whole bridge by a remarkable progress of local corrosion. Besides, it is undesirable in respect of an environmental impact to remove comparatively sound paint film.

Then, NILIM examined the method which enables to repaint only local deterioration part in high quality. This research shows development of the surface preparation method by open-blast cleaning in combination with power tool and specifications for partial re-painting which is superior in durability of the boundary part between existing paint and re-paint film, with the verification of their practicability.

1. INTRODUCTION

The paint film which contributes to corrosion prevention is deteriorated as time passes, and the deterioration will lead to corrosion of the steel member in due course. It is supposed that there is a great difference in the corrosive environment between at the span center and at the end support point surrounded by deck slab, abutment, pier and bearing.

In fact, a lot of cases that local corrosion occurs at the edge of girder are reported (Picture-1.1), because the space is poorly ventilated and humid due to leakage water from the expansion joint and sand deposit on the bridge seat. As a result of statistical analysis on the correlation between the point of the span and its corrosion state based on bridge inspection data, the parts excluding support points corrod in only 9.5% (87 bridges) of all analyzed bridges (914 bridges), and Figure-1.1 shows the parts at support points such as abutments and piers corrode more often than span center of the girder.

Therefore, paint deterioration and corrosion tend to progress not uniformly but partially at the narrow parts such as edges of steel girders.

PICTURE-1.1 Examples of corrosion at the edge of steel girder [1]

2. INFLUENCE OF LOCAL CORROSION

Commonly, the progress speed of the whole bridge corrosion due to paint deterioration is slow to greatly affect its soundness. On the other hand, the progress speed of local corrosion which concentrates at a certain part due to uneven environment becomes far higher than the whole bridge corrosion. According to the degree of local corrosion, it can affect the soundness of the whole bridge.

Then, we analyzed an influence of local corrosion according to degree on a load capacity of steel member by modeling corrosion patterns of the edge of girder based on examples of past damage.

Analysis cases are as shown in Table-2.1, and each case is evaluated with buckling position of steel member and reduction ratio of buckling eigenvalue by vertical loading. Analysis models are as shown in Figure-2.1. In this connection, bearings on the end is set as fixed condition because in most cases it is confirmed based on bridge inspection data that they are not movable due to corrosion between bearings and sole plates.

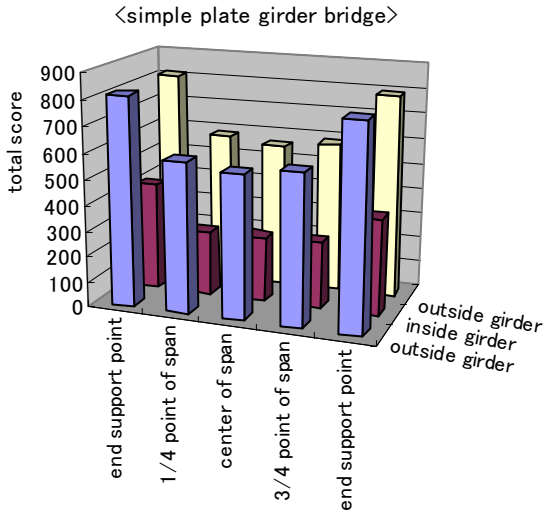
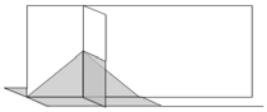
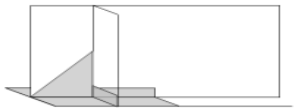
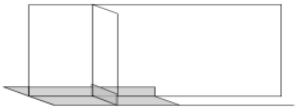


FIGURE-1.1 Corrosion frequency according to point of the span

TABLE-2.1 Analysis cases

	Case A1	Case A2	Case A3
Corrosion pattern			
Thickness reduction ratio	25 %		
	50 %		
	75 %		

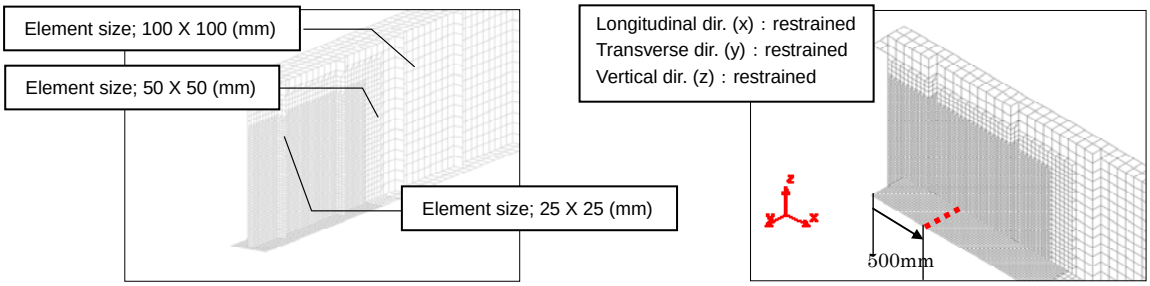
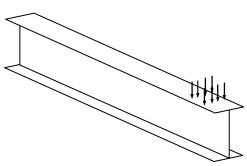
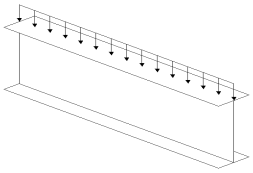
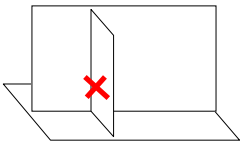
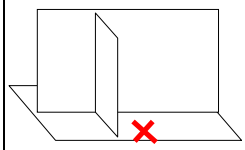
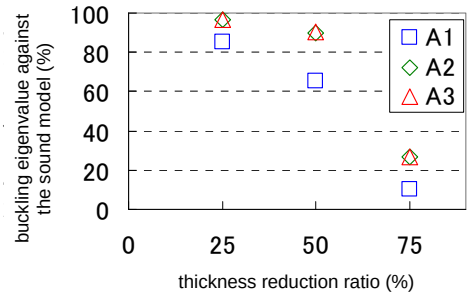
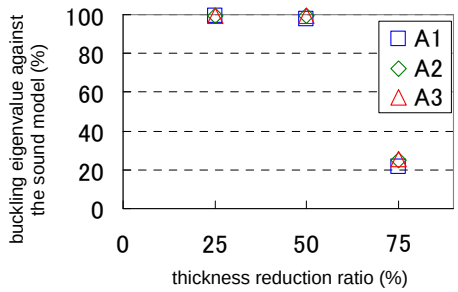


FIGURE-2.1 Analysis model

Results of the analysis are shown in Table 2.2. When the thickness reduction ratio was 25% or 50%, buckling eigenvalue was not different from that of sound model. But it reached a certain value, buckling eigenvalue suddenly decreased. This was because changing of the sectional area of vertical stiffener greatly affected local buckling of a steel member.

Therefore, it was confirmed that the degree of local corrosion at the edge of girder greatly affects a load capacity of the bridge. At the parts where the local corrosion tends to occur, it is important to implement structural countermeasure for proper drainage and also to establish the method which enables to repaint only these parts in high quality on bridge management.

TABLE-2.2　Result of the analysis

	Vs（Vertical load・on the support point）	V（Vertical direction）
Loading type	 Loading area 0.4 m × 0.2 m = 0.08 m^2 Distributed load strength 100 kN / 0.08 m2 = 1.25 N/mm^2	 Distributed load strength = 1 kN/m^2
Buckling position	 Thickness reduction ratio 25% Local buckling (A1: vertical stiffener, A2, A3: web) 50% 〃 75% Local buckling (A1～A3: lower flange)	 Case A1～A3 Thickness reduction ratio 25% Lateral buckling 50% 〃 75% Local buckling (Lower flange)
Reduction ratio of buckling eigenvalue		

3.　PROPOSAL OF PARTIAL RE-PAINTING METHOD

For the methods to renew bridge paint film, common points to note have ever been indicated in some technical materials, but not been limited to the parts where local deterioration and corrosion tend to progress. [2]

Then, we considered the partial re-painting method which enables to repaint only these parts in high quality based on examples of past damage and bridge inspection data. Some main contents are shown below;

1)　Selection of partial re-painting method

When the bridge re-painting is planned, it is necessary to verify its effectiveness based on the state of paint deterioration and corrosion from the results of bridge inspection and investigation.

It should be properly decided whether the partial re-painting is selected or whole the bridge re-painting, based on the verification of bridge construction environment, re-painting record, the degree of damage and economy in which the future maintenance is considered.

2)　Specifications for partial re-painting

The narrow parts, such as the edge of steel girder where the deterioration is remarkable, have a weakness from the view point of rust / corrosion prevention due to leakage and dew formation. Moreover, the work efficiency at these parts is inferior to other common parts. And so, frequently repeating the re-painting is not only uneconomical but also influential on society due to noise by surface preparation and traffic regulation.

Therefore, the re-paint specification should be heavy duty coating which is superior in durability as shown in Table-3.1. The specification, however, is different according to the coating system of existing paint film. In this connection, the lap on boundary part between existing paint and re-paint film is always needed not to expose the substrate of steel member.

TABLE-3.1　Representative specification for partial re-painting [2]

Coating Process	Existing coating system (A -type)	Re-paint coating system		
		Paint name	Application Rate (g/m^2)	Interval between coats
Surface preparation	Blast cleaning (SIS Sa 2.5、SPSS Sd 2・Sh 2)	Blast cleaning and other methods (Equivalent to ISO Sa 2.5)		Within 4 hours
Under coat		Organic zinc-rich paint	600	
Under coat	Lead anti-corrosive paint (1^{st})	Weak solvent type of modified epoxy resin paint for under coat	240	1～10 days
Under coat	Lead anti-corrosive paint (1^{st})	Weak solvent type of modified epoxy resin paint for under coat	240	1～10 days
Intermediate coat	Long oil phthalic resin coating for intermediate coat	Weak solvent type of fluorine resin paint for intermediate coat	170	1～10 days
Top coat	Long oil phthalic resin coating for top coat	Weak solvent type of fluorine resin paint for top coat	170	1～10 days

3)　Method and the glade of surface preparation

In order to implement partial re-painting in high quality (the glade equivalent to ISO Sa 2.5), it is necessary to remove existing paint film perfectly with the surface preparation by using blast cleaning and other methods. In the case that the surface preparation is implemented at the connection of high tensile bolt, the corner of member or other uneven parts, it is high possible that deteriorated paint film and rust are not removed sufficiently because abrasive cannot hit these parts.

Therefore, it is necessary to pay attention to remove deteriorated paint and rust left by the blast cleaning method in combination with a power tool. In this connection, the surface preparation at existing paint film lapped may be to the extent that the dirt on the surface of paint film is washed off.

4)　Decision of partial re-painting area

The end space of bridge is poorly ventilated and humid due to leakage water from the expansion joint, failure of roadway drainage, and other factor. This indicates the edge of girder is the part which is exposed under the severest corrosive environment.

Therefore, the area of girder on the bridge seat as shown in Figure-3.1 should be decided as the minimum range to implement the partial re-painting. Moreover, it is desirable to include the area where enough space under the bridge girder cannot be secured due to geographical features or others.

In case that deteriorated parts are spotted within the small-scale range, it should not be allowed to adopt touch-up painting for local repair as possible from the viewpoint of quality securing, because it has difficulty to manage these parts in distinction from other parts. So, it is desirable to implement re-painting a certain range together as shown in Figure-3.2.

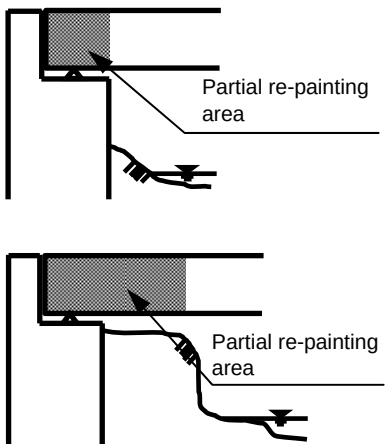


FIGURE-3.1　partial re-painting area

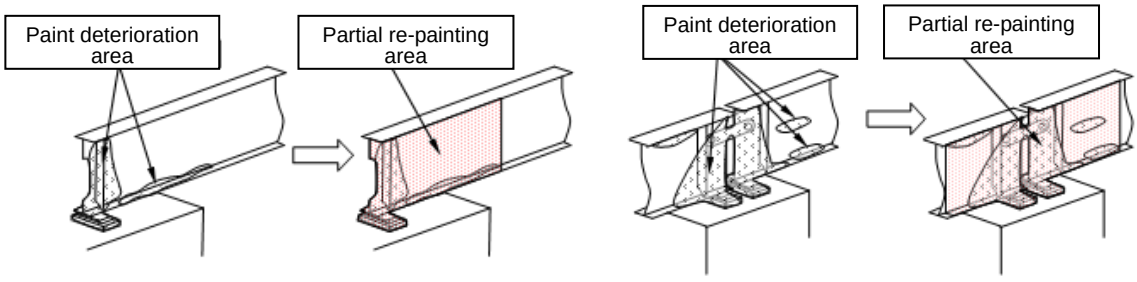


FIGURE-3.2　Examples of re-painting area according to deterioration parts

4. WORKABILITY EVALUARION EXAMINATION

In order to verify the effectiveness of the surface preparation and the partial re-painting proposed in Chapter 3, the workability evaluation examination with 4 specimens was conducted. The specimen was made in main girders (about 2.5m length from the end) of removed bridge. The size of the specimen is as shown in Figure-4.1 and the state after construction is as shown in Picture-4.1.

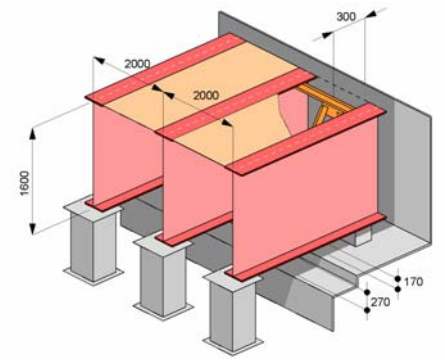


FIGURE-4.1 Size of the specimen

PICTURE-4.1 State of the specimen

1) Workability of surface preparation at the narrow parts

The examination was conducted to verify the workability of surface preparation with single or combination of methods shown in Table-4.1.

TABLE-4.1 Surface preparation methods

Surface preparation method	Outline
Open-blast cleaning	Worker conducts the blast cleaning with directly operating a nozzle at the space which is all over enclosed by the sheet for the purpose of preventing the scattering of abrasive.
Vacuum blast cleaning	Abrasive is collected by suction power in a nozzle while jetted against the object part for the purpose of preventing the scattering.
Compact blast machine	A nozzle diameter is smaller than usual one to enable the blast cleaning at the narrow parts, and this machine is used in combination with other blast cleaning method or power tool.
Power tool	Brush cup wire, High-speed milling cutter, Rotary grinder, and Disk sander, etc.

The results of the examination which was conducted at upper installation part of the end sway bracing were as follows

●CASE1： Surface preparation by power tool

It was possible to finish up the part surrounding the bolt head and other narrow parts at the connection of members by a compact machine such as the rotary grinder. Preparation area was over 95 % of the object, and the grade was equivalent to ISO St 2 or St 3.

●CASE2： Surface preparation by vacuum blast cleaning

It was possible to conduct the blast cleaning against flat part, but at the flange of channel member and the corner where enough space was not secured because a vacuum blast nozzle interfered, the work was impossible. Preparation area was approximately 75 % of the object, and the grade was equivalent to ISO Sa 2.5 at worked parts.

●CASE3： Surface preparation by open-blast cleaning

It was possible to conduct the blast cleaning at the area where the object could be identified visually. However, it was somewhat sufficient at the part surrounding the bolt head and other narrow parts at the connection of members. Preparation area was over 95 % of the object, and the grade was equivalent to ISO Sa 2.5.

●CASE4： Surface preparation by open-blast cleaning in combination with compact blast

It was possible to conduct the blast cleaning at the major part of the area. Moreover, it was useful to combine with compact blast machine at the part surrounding the bolt head and other narrow parts at the connection of members. Preparation area was over 98 % of the object, and the grade was equivalent to ISO Sa 2.5.

●CASE5： Surface preparation by open-blast cleaning in combination with power tool

It was possible to conduct the blast cleaning at the major part of the area. Moreover, it was useful to combine with power tool at the part surrounding the bolt head and other narrow parts at the connection of members. Preparation area was over 98 % of the object, and the grade was equivalent to ISO Sa 2.5 at the area worked by blast and St 3 at the area worked by power tool.

The following have been confirmed from the results of the workability evaluation examination for the surface preparation.

- The grade needed for surface preparation cannot be secured with only power tool method.
- Vacuum blast cleaning method is useful from the point of preventing the scattering of abrasive, but it is difficult to apply the method to the part where the vacuum nozzle interfered physically.
- It was confirmed that open-blast cleaning method enables the surface preparation with the grade equivalent to ISO Sa 2.5 at the major part. Besides, it was effective to combine with power tool or compact blast machine at the part surrounding the bolt head and other narrow parts at the connection of members where existing paint film tends to remain.

2) Workability of partial re-painting

In the partial re-painting, it is necessary to lap a new paint on existing paint film. Commonly, some problems such as peeling, blistering, cracking, and dissolution can occur according to the compatibility of combination of paint film.

Then, in order to verify the workability of re-painting at the lap part, pull-off test and outdoor exposure examination were conducted. As shown in Figure-4.2, the partial re-painting was at the area of 600 mm in width and 200 mm in height on the web of main girder. The left half of the area was conducted the surface preparation, and a new paint was lapped on existing paint film left on the right half. The specifications for re-painting were selected 5 kinds (only under coat) as shown in Table-4.2 according to paint material and painting method.

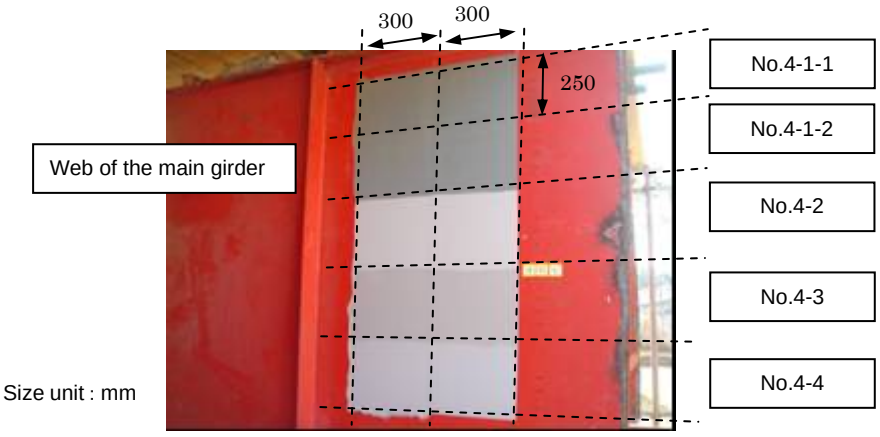


FIGURE-4.2 The state of partial re-painting on the web

TABLE-4.2 Coating systems of existing paint and re-paint film

Coating Process	Existing paint film	Test No.	Re-paint film
Under coat	Lead anti-corrosive paint	4-1-1	Organic zinc-rich paint（by spray）
		4-1-2	Organic zinc-rich paint（by brush）
		4-2	Weak solvent type of modified epoxy resin paint for under coat（by brush）
		4-3	Non-solvent type of modified epoxy resin paint for under coat（by brush）
		4-4	Strong solvent type of modified epoxy resin paint for under coat（by brush）
Intermediate coat	Long oil phthalic resin coating for intermediate coat	Not coated	
Top coat	Long oil phthalic resin coating for top coat	Not coated	

【Adhesion at the lap part】

In order to verify the adhesion of paint film at the lap on boundary between existing paint and re-paint film, the Pull-off test was conducted at the time when 3 months passed after re-painting.

Pull-off test is the method to evaluate the adhesive strength of the paint film by measuring a minimum tension needed for peeling or tearing in the vertical direction against the test plate. As shown in Figure-4.3, the test cylinder spread the adhesive (bond) uniformly is touched to the paint film, and is left until stiffening. Then, the tension is added vertically to the surface of the paint film and the adhesive strength measured until the failure is classified in Table-4.3.

The results of pull-off test are shown in Table-4.4.

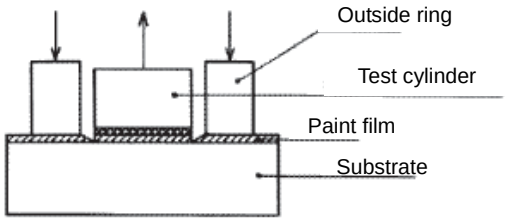


FIGURE-4.3 Pull-off test [3]

TABLE-4.3 Evaluation score [4]

Evaluation score	Adhesive strength (MPa)
0	$2.0 \leqq X$
1	$1.0 \leqq X < 2.0$
2	$0 < X < 1.0$
3	$X = 0$

TABLE-4.4 Results of the pull-off test at the lap part

Test No.	Paint specification		Adhesive strength (N/mm^2)	Peeling part	Peeling state	
	Existing paint film	Re-paint film			Test piece side	Test cylinder side
4-1-1-R	A-type coating system	Organic zinc-rich paint (by spray)	3.5	Tool／Adhesive 10% Re-paint film 5% (cohesive) Exsiting paint film 85% (cohesive)		
4-1-2-R	A-type coating system	Organic zinc-rich paint (by brush)	3	Tool／Adhesive 30% Existing paint film 70% (cohesive)		
4-2-R	A-type coating system	Weak solvent type of modified epoxy resin paint (by brush)	3.5	Adhesive／Re-paint film 50% Re-paint film 10% (cohesive) Existing paint film 40% (cohesive)		
4-3-R	A-type coating system	Non-solvent type of modified epoxy resin paint (by brush)	3	Tool／Adhesive 5% Re-paint film 60% (cohesive) Adhesive／Re-paint film 35%		
4-4-R	A-type coating system	Strong solvent type of modified epoxy resin paint (by brush)	3	Tool／Adhesive 15% Adhesive 20% (cohesive) Existing paint film 65% (cohesive)		

The following have been confirmed from the results of the adhesion evaluation test at the lap part.

- The adhesion strength of paint film at the lap part was over 2.0 MPa in all cases.
- The adhesive failure between existing and re-paint film has not been confirmed in this test.
- It was confirmed that the adhesion was enough at the time when 3 months passed after the partial re-painting. However, long-term adhesion has not been clarified. So it is necessary to verify it at another time.

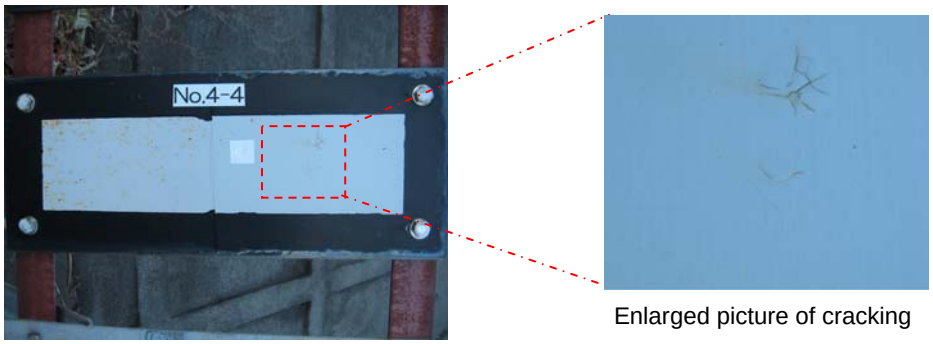
3) Durability of partial re-painting

In order to verify the durability of paint film at the lap on boundary between existing paint and re-paint film, the outdoor exposure examination is being conducted with the test piece cut off from the specimen used in the adhesion evaluation test. The location is along the coast Sea of Japan (Picture-4.2), and about 1.5 years have passed on May, 2009 since the beginning of the exposure.

PICTURE-4.2 Exposure examination

Picture-4.3 shows the state of the test piece at the time when about 1 year passed after the beginning. In this connection, the test number of each test piece is the same as Table-4.3 and a new paint has been lapped on existing paint film left on the right half, then.

In most cases, remarkable deterioration has not been confirmed visually, but in the case of using strong solvent, the cracking which is supposed to be caused by lifting (the phenomenon that a new paint solvent attacks existing paint film and floating occurs) was confirmed. Commonly, a strong solvent type is not in use as top coat because it can cause the lifting, so it is supposed that the type is also not suitable to the specification for partial re-painting in which the lap part is needed on boundary between existing paint and re-paint film.



PICTURE-4.3 State of the test piece（1 year after the beginning of the exposure）

5. TRIAL WORK AT EXISTING BRIDGE

For the partial re-painting method which was proposed in Chapter 3 and was confirmed its workability in Chapter 4, the practicability was verified with the trial work at existing bridge. The outlines of coating process and working management plan are as shown in Figure-5.1 and Table-5.1.

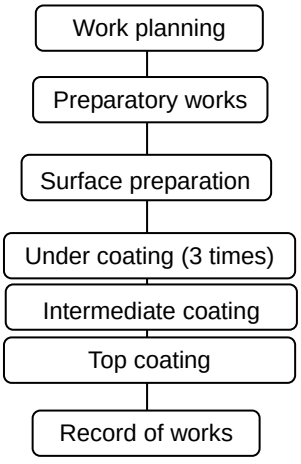


FIGURE-5.1 Work flow

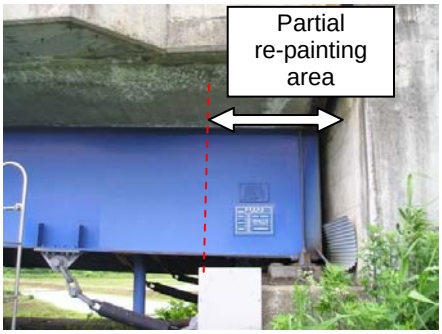
TABLE-5.1 Outline of working management

Item	Contents
Process management	・management of progress with bar chart of the work
Quality control	・Quality of the paint is confirmed with the test score and sample ・Measurement of temperature and moisture（2 times / day） ・Condition for work discontinuance ; Temperature, Weather（hot・rainy, moisture, wind speed, Dust, and other factor ・Management of interval between coats, dilution ratio and pot-life
Progress control of working form	・Confirmation of application rate according to the coat ・Confirmation of target thickness
Film thickness control	・Measurement timing of thickness, Standard for measurement, and Standard for management

1) Decision of re-painting area

Picture-5.1 shows the state before the partial re-painting work. The bridge for trial is located far from the coastline, is surrounded by the fields, and is well ventilated. So, paint deterioration and corrosion is not remarkable.

The area for the partial re-painting was decided about 1m range from the end in this case.



PICUTURE-5.1 Before the work

2) Surface preparation

For trial, open-blast cleaning method was adopted as the surface preparation. The edge of girder was all over enclosed by the blue sheet as shown in Picture-5.2 for the purpose of preventing the noise and the scattering of dust and spent abrasive. It was difficult to prevent them perfectly, but there were not complaints because of enough distance from the residence in this case.

It was confirmed that the surface preparation by using open-blast cleaning method was able to be conducted without the rest of existing paint film and fixed rust. In this connection, however, the recovery rate of used abrasive is about 60 or 80 % of all with a shovel and a cleaner, and they had to be dealt with as the industrial waste due to the poisonous metal such as lead included in the paint film.

PICTURE-5.2 Open-blast cleaning

PICTURE-5.3 Result of the blast cleaning

3) Partial re-painting

The painting work of the under coat was divided into two times for the purpose of preventing dripping, and in fact, the paint was needed more than the application rate to secure the target thickness because it soaked in uneven substrate after the blast cleaning.

On the boundary, at first, existing film was washed the dirt off and undertaken the masking. Then, a new paint was lapped about 10 mm range on existing paint.

Besides, the color of the re-paint material was selected similarly to existing paint from the viewpoint of aesthetic as shown in Picture-5.4.

PICTURE-5.4 After the work

The following have been confirmed from the results of the trial work of the partial re-painting at existing bridge.

- It is necessary to management the work sufficiently for the renewal of bridge paint film in high quality.
- It is necessary to enclose the object parts of the open-blast cleaning with the sheet or the board fence for the purpose of preventing noise and scattering of dust and spent abrasive. Especially, it should be considered carefully in the urban district near to residence.
- Open-blast cleaning method was able to be applied in the surface preparation at the narrow parts such as the edge of girder. However, it was necessary to take care about the disposal of used abrasive in the case that the poisonous metal was included in the paint film.

- It is necessary to take care that the paint more than the application rate might be needed to secure the target thickness due to the feature that the paint for under coat tends to soak in uneven substrate after the blast cleaning.
- The re-paint film was able to be lapped properly on existing paint film. However, at present, its durability should be verified individually.

6. CONCLUSION

In this research, the following were clarified.

- Paint deterioration and corrosion tend to progress not uniformly but partially at the narrow parts such as edges of steel girders based on examples of past damage and the inspection data.

- As a result of the analysis by modeling corrosion patterns of the edge of girder, it was clarified that the degree of local corrosion greatly affects a load capacity of the bridge. Therefore, it is necessary to implement structural countermeasure for proper drainage and re-painting which enables to repaint only these parts in high quality on bridge management.

- As a result of the workability evaluation examination, it was effective to implement the surface preparation by using open-blast cleaning method in combination with power tool etc. for securing high preparation grade.

- As a result of the adhesion evaluation test at the lap part on boundary between existing paint and re-paint film, the adhesion was enough at the time when 3 months passed after the partial re-painting on the assumption of proper recoatability. As for long-term durability, we are going to continue the exposure examination.

- As a result of trial work at existing bridge, the surface preparation and the partial re-painting proposed in this research have been able to be applied in enough quality.

Finally, specifications of partial re-painting including surface preparation method for steel bridges based on this research are going to be arranged as a technical manual in NILIM.

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